A Digital Model of a Dwell Mechanism for Alpha-Stirling Engine

N.M. Dehelean, V. Ciupe, and E.C. Lovasz

Abstract The paper shows a digital model of a dwell mechanism dedicated to an α-Stirling Engine. The low efficiency of an α-Stirling Engine drives us to improve on its work characteristics in order to rise-up its efficiency [2]. The main way to achieve this is to improve the engine characteristics. There are a lot of mechanisms species that could be used to obtain a dwell movement function that is necessary to the compression cylinder. A bar mechanism could be more reliable than cam mechanism despite that the cam mechanism is more precise. The bar mechanism presented in this paper has seven bars but seems to be reliable enough for this application. There are other ways to improve the efficiency, to change the working gas from the cylinders. A good efficiency is obtained using a gas that has a high specific heat, like hydrogen or helium.

Keywords Bar mechanism · Dwell mechanism · Simulation · Stirling engine

1 Introduction

The first stage of movement function evaluation starts from the mechanism configuration that is shown in paper [1]. In order to evaluate the active and resistant torque at the compression rod it is necessary to reveal the reduced torque expression coming from the movement function and estimated forces applied on the piston in the compression cylinder. The real torque will be obtained using the pressure diagram acquired from a physical model.

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2 The Kinetostatic Analysis of the Mechanism

In order to be able to perform an appropriate simulation, the mechanism described in [1] must be further analysed. The active and reactive forces that appear in the mechanism are represented in Fig. 1. Active forces appearing in the compression cylinder are displayed in Fig. 2, where:

F_7 – active force provide by expansion cylinder
F_6 – passive force provide by compression cylinder
M_1 – active torque
M_2 – resistant torque

From the above graphics some relations can be deduced in order to extract the movement functions of both expansion and compression cylinder (y_E and y_C) and also for the torque present at the crank of the expansion cylinder:

$$M = M_1 + M_2 \tag{1}$$

$$M_1 = F_7' \, a \tag{2}$$

$$F_7' = \frac{F_7}{\cos \alpha} \tag{3}$$

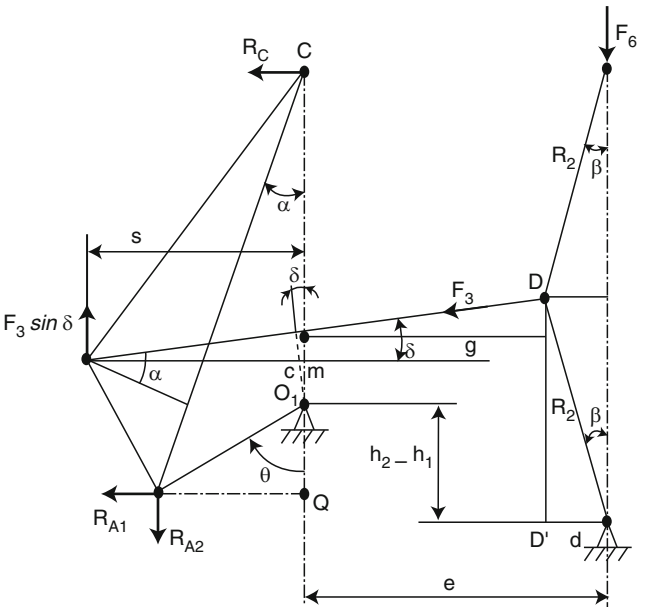

Fig. 1 Kinetostatics of the mechanism

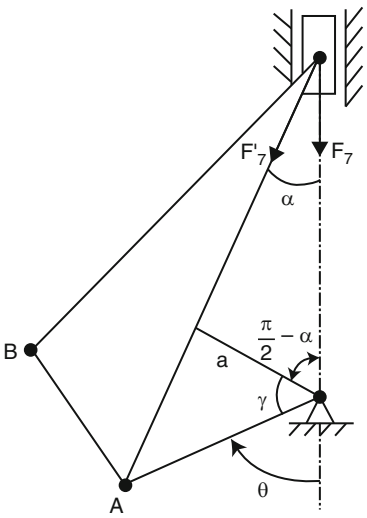

Fig. 2 Forces in the compression cylinder

$$\gamma = \frac{\pi}{2} + \alpha - \theta \tag{4}$$

$$a = r_{c\,rod}\ \cos\gamma \tag{5}$$

$$M_1 = \frac{F_7}{\cos\alpha}\ r_{c\,rod}\ \cos\left(\frac{\pi}{2} + \alpha - \theta\right) \tag{6}$$

and resulting from the force equilibrium in joint 'D:

$$F_3 = \frac{2\,F_6\ \tan\beta}{\cos\delta} \tag{7}$$

From the equation system (9), presented in [1] the angle δ can be determined:

$$\tan\delta = \frac{h_2 - y_B - R_2\ \cos\beta}{x_B + R_2\ \sin\beta - e} \tag{8}$$

$$d = R_2\ \sin\beta\ ; \quad DD' = R_2\ \cos\beta \tag{9}$$

$$m = DD' - (h_2 - h_1) - (e - d)\ \tan\delta \tag{10}$$

$$m = R_2\ \cos\beta - h_2 + h_1 - (e - d)\ \tan\delta \tag{11}$$

$$M_2 = R_{A2}\,R_{c\,rod}\ \sin\theta - R_{A1}\,R_{c\,rod}\ \cos\theta \tag{12}$$

$$\begin{cases} R_{A1} + R_C = F_3 \cos\delta \\ F_3 \cos\delta \ (m + R_{c\,rod}\cos\theta) - \\ -R_C(b \cos\alpha - m - R_{c\,rod}\cos\theta) = 0 \end{cases} \tag{13}$$

Some substitutions must be applied:

$$p = m + R_{c\,rod} \cos\theta\,; \quad F_{3H} = F_3 \cos\delta \tag{14}$$

and the system becomes:

$$\begin{cases} R_{A1} + R_C = F_{3H} \\ F_{3H}\, p - R_C \ (b \cos\alpha - p) = 0 \end{cases} \tag{15}$$

$$R_{A1} = F_{3H} - R_C \tag{15'}$$

The joint 'C' does not support load on the 'o-y' (vertical) direction, so the following equation can be expressed:

$$F_3 \sin\delta \left(\frac{b_1}{\cos\alpha} + (b \cos\alpha - p) \tan\alpha \right) = R_{A2}\, R_{c\,rod} \sin\theta \tag{16}$$

The right hand term being a component of M_2, the equation of M_2 is:

$$\begin{aligned} M_2 = F_3 \sin\delta \left(\frac{b_1}{\cos\alpha} + (b \cos\alpha - p) \tan\alpha \right) - \\ - R_{A1}\, R_{c\,rod} \cos\theta \end{aligned} \tag{17}$$

3 Digital Simulations of the Dwell Mechanism

By making use of the relations obtained above, a numeric simulation of the mechanism can be conducted. Figure 3 shows the movement functions and phases of the two cylinders and also the torque obtained at the crank of the expansion cylinder. The known parameters, forces, dimensions and compression ratio are imposed for this simulation.

The torque diagram shows that the mechanism provides an active torque on an angle sweep from 0° to 32° (detail D in Fig. 3). This offers an advantage to move out the engine from top dead center.

Integrating the both areas under the torque curve it obtains a ratio between the active and the resistant torque on a work cycle. This ratio is only an evaluation that could be used further on (Fig. 4).

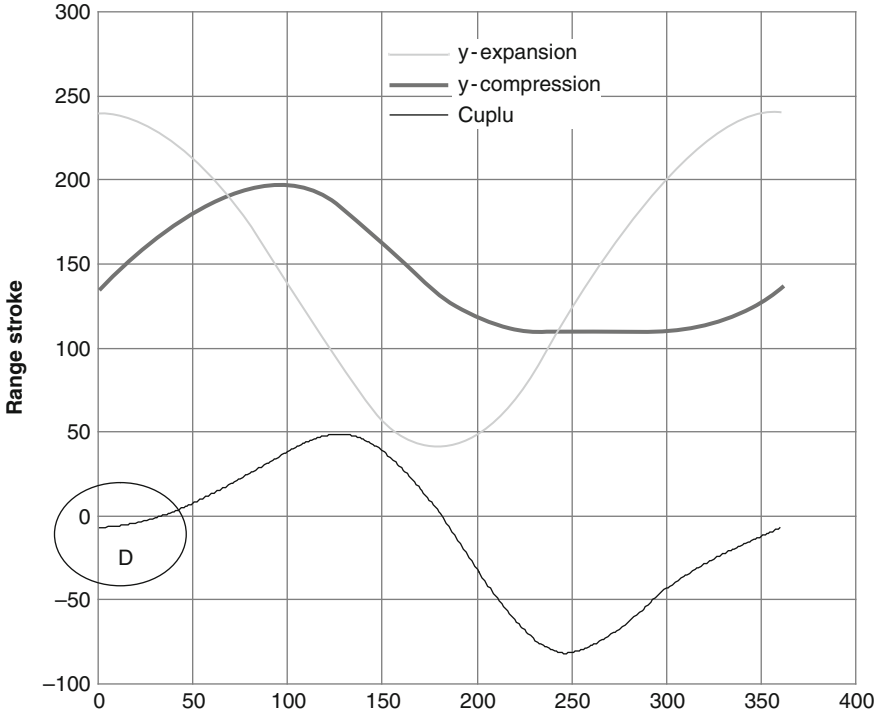

Fig. 3 Piston movement functions

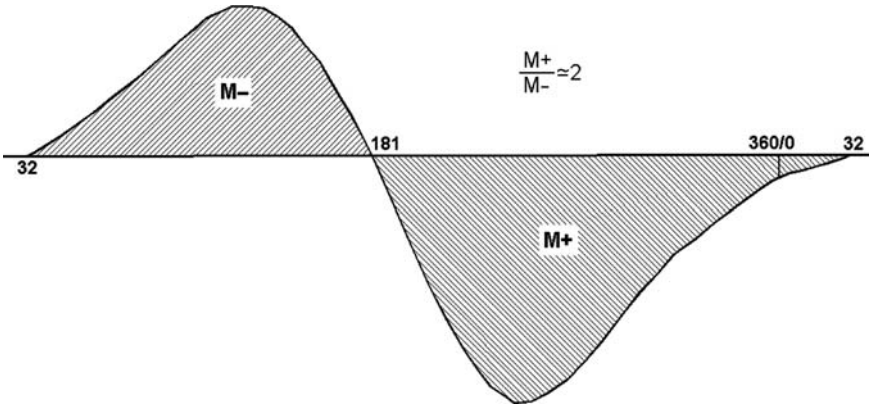

Fig. 4 Compression piston's crank torque

According to the paper intention, accuracy improvement of the mechanism simulation, it was used a specialized German simulation software ("Kosim") that provides displacement, speed, acceleration and force function graphs for a full turn of the mechanism (Figs. 5, 6, and 7).

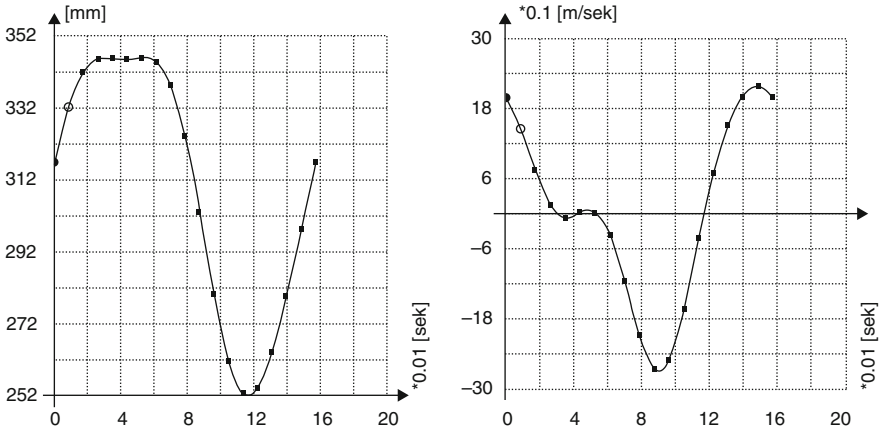

Fig. 5 Expansion piston displacement and velocity functions

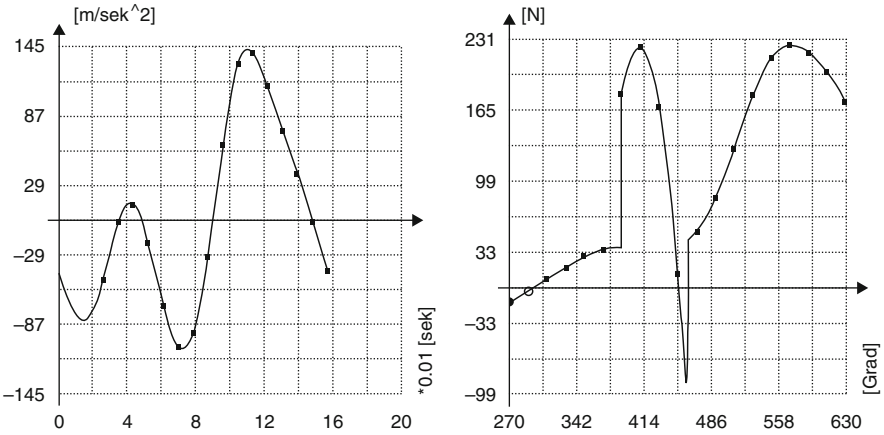

Fig. 6 Expansion piston acceleration and reactive force

It can be observed that velocity is not strictly 0 on the dwell angle period. That is true because the dwell is not strictly a stop displacement and could be observed if it increases the scale of diagram representation.

The target of the paper is to evaluate that the new mechanism is better then a classic crank-shaft one for the use in Stirling engines. Therefore it is necessary to evaluate the forces, torques, mechanical work on a complete work cycle [3]. For this reason Fig. 7 contains a complete working cycle representation, not only the dwell period.

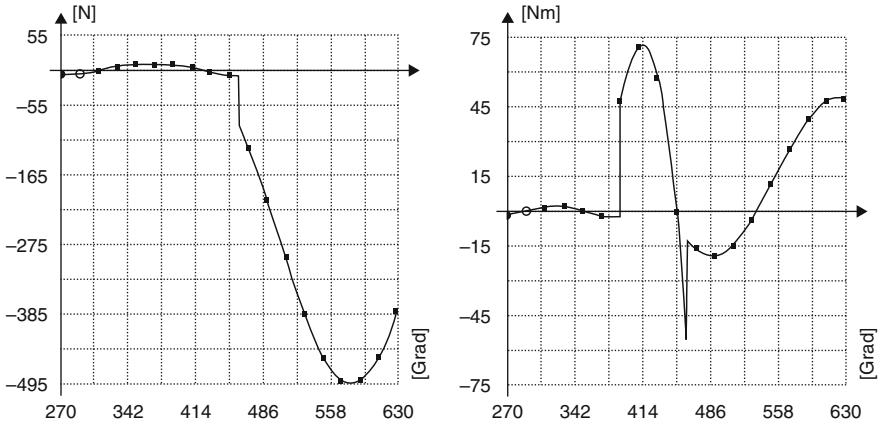

Fig. 7 Compression piston reactive force and crank torque

4 Conclusion

The simulations of the mechanism prove that the proposed technical solution is appropriate to be embedded in an α-Stirling engine structure. This is expected to provide a better displacement, speed and acceleration functions than cam mechanisms. The accuracy of the deduced relations is sustained by the use of mechanism dedicated software also the movement function graphs based on these calculations. Also the high amount of positive torque obtained brings up the advantages of the proposed mechanism design and drives us into further research in this field. The full validation of the mechanism will be revealed on the real prototype.

References

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